Detection of Coincidences and Generation of Hypotheses – a Proposal for an Elementary Cortical Function

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Abstract

A framework for a model of elementary cortical function is presented which is based on the detection of coincident events by intracortical processing. By extracting coincidences knowlegde about the rules of interaction with the environment can be acquired. Vice versa this knowledge can be used for the generation of anticipatory hypotheses and hypotheses about ambiguous data. Some basic functions of visual recognition could be explained by this model if recognition is considered to be in strong connection with motoric action.

1. Introduction

Our model is insprired by the former work of BARLOW who supposed that the detection of 'suspicious coincidences' in afferent data streams could be a basic cortical function [1, 6]. Coincident events occur more often combined than it can be expected from their single probabilities; they therefore should reflect causal connections of reality. Coincidence detectors operate on information from sensory sources and internal states, e.g. between visual impression and tactile stimuli or between generated motor commands and information from proprioceptive sensors.

2. Evidence from physiology

Detection of coincidences is supposed to be a function performed everywhere in the cerebral cortex in a similar manner. There is some evidence from physiology for a common cortical function, even if the developed cortex shows significant differences in the architectonic features of the areas. The structure of the developing protocortex is relatively uniform [5], only afferent and efferent fibers are arranged specifically. Afferent inputs cause structural and functional modifications of the areas according to the *spatiotemporal structure of the data*. If fibers of a certain modality are redirected to an area which normally processes another modality, the new function can be performed by this area. In terms of our hypotheses: cortical areas own all equipment necessary for the detection of a wide range of coincidences. What coincidences the area specializes in is decided by area-specific inputs; e.g. if especially temporal relations have to be considered, units providing a specific time behaviour will be integrated and others will be discarded. Because it is impossible to detect coincidences between all channels, the information streams to be combined are defined genetically; each area can only detect coincidences on a combination of channels that proved to be necessary during evolution [1]. Experiments with kittens [7] demonstrated the variability of coincidence detection within the genetic frame; some cells showed responses to a combination of signals that was never found in normal kittens.

3. Detection of coincidences and generation of hypotheses

Up to a certain stage of processing coincidence detecting units only *signal* the occurence of a known combination of events they are specialized in to higher levels of recognition (e.g. formation of orientation–sensitive cells [4]). In higher levels events which have been detected to be coincident seem to feed back mutually. An example: If you start moving, your sensors are regularly confronted with a connection of two impressions: all visual features move with growing velocity in certain directions and sensors of your body report the 'feeling' of acceleration. Because this combination is a main property of our physical world it occurs in (almost) all cases; it is then integrated into the internal model of the world. Sitting in a train you are now confronted with a well-known phenomenon: if a train next to yours drives up, you see the change of the visual features and *feel* the acceleration of your train although there is none; the occurence of *one* of the events sets up a hypothesis about the others. We don't move ourselves but we have a *conception* about movement derived from the coincidence between visual impression and the sensation of real movement. In our terminology this can be called a *completing hypothesis*.

Figure 1 shows the neural basis of the detection of coincidences and the generation of hypotheses. If two events often occur *at the same time*, a *completing hypothesis* can be created (**figure 1, III**) by symmetrical excitatory connections between 'hypotheses–cells', even if only *one* information is present. Two events in a *fixed temporal relation* that reflects a causal connection, e.g. a visual impression of an object together with a certain motor command and a tactile information when a limb touches the object, should result in asymmetrical weights between the 'hypotheses–cells' (**figure 1, IV**). Presentation of the 'cause–event' sets up an *anticipatory hypothesis* about the 'effect–event', whereas it is impossible to draw the opposite conclusion.
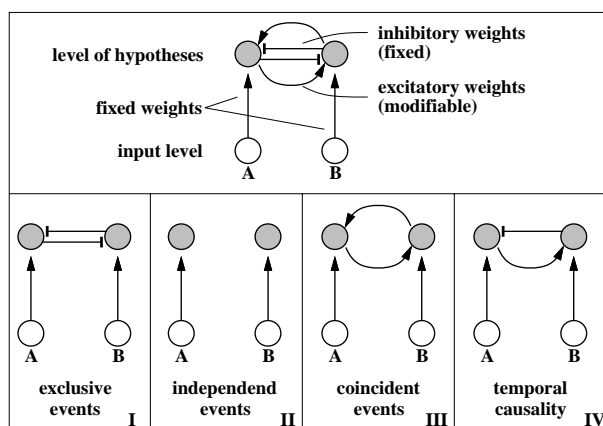

Figure1: **Upper part:** Two 'hypotheses–cells' are mutually connected by fixed inhibitory and modifiable excitatory weights. The efficiency of the excitatory connections is high, if the events **A** and **B** are coincident. **Lower part:** Possible interaction of 'hypotheses–cells'. (**I**) Exclusive events. Excitatory weights vanish. (**II**) Independend events. Excitatory and inhibitory effect are balanced. (**III**) Coincident events. Excitatory effect predominates. (**IV**) Event **A** often precedes **B**. Weights become asymmetric.

'Hypotheses–cells' transmit input signals as well as hypotheses. If HEBB–like learning is applied for the modifikation of the synaptic connections between them, excitation by hypotheses and by input information has to be distinguished in the learning rule. Excitation of one 'hypotheses–cell' by another, which is not excited by 'real' input, should not be interpreted as a coincidence of two events. A possible explanation could be the assumption of *separated ranges* for input activity (above a certain level) and activity induced by hypotheses (below this level) [2]. Strengthening of synapses is restricted to cases, when both the presynaptic and postsynaptic cell are excited above this level. Distinct pathways (e.g. axo–somatic synapses for input transmission and axo–dendritic for hypotheses) could be postulated to preserve the source of activation through all processing levels.

Interconnected 'hypotheses–cells' take part in two major generation processes of hypotheses:

1. *Generation of sequences of hypotheses:* We assume the events **A** and **B** to be 'coincident' (in this case they occur in a fixed temporal relation) as well as **B** and **C** (see **figure 2**, left part). If only **A** occurs, **A**'s 'hypotheses–cell' is excited by the input and itself excites the 'hypotheses–cell' of **B**: a hypotheses about **B** is set up. **B** itself, which is *a hypothesis only* because the input cell of **B** is not active, is able to set up a hypotheses **C** and so on — a sequence of events can be predicted this way.

2. *Harmonization of hypotheses on ambiguous data:* Ambiguous data (such as the retinal image of one eye) lead to different sets of hypotheses about the real situation, some of them being *consistent*, the others *inconsistent*. If a set of hypotheses is inconsistent, there are active 'hypotheses–neurons' inhibiting each other. In the simplest case these cells represent complementary events (see **figure 2**, right part). In a relaxation process inconsistences could be solved by switching on or off some of the 'hypotheses–cells', a process comparable to relaxation in feedback associative memories. In **figure 2** event **A** and **B** favour **C**, whereas **D** is coincident with the complementary event of **C**. A hypotheses including an event and its complementary event is inconsistent and should be changed by deactivating one of the 'hypotheses–cells'. Inconsistences like the one shown in the right part of **figure 2** are solved by majority decision.
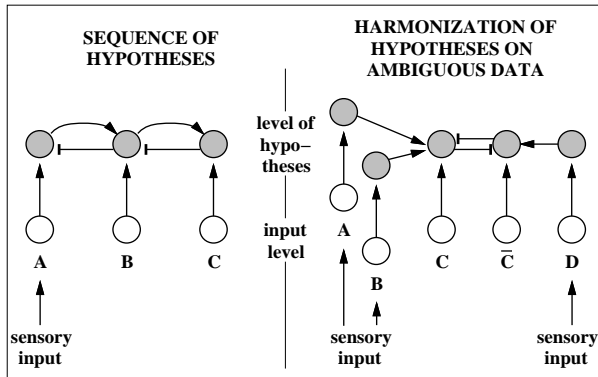

Figure2: The two major generation processes of hypotheses. **Left part:** Generation of sequences brings about the prediction of a chain of subsequent events. In this case 'hypotheses'–cells excite each other. **Right part:** The harmonization of hypotheses solves inconsistences in sets of hypotheses on ambiguous data. Inhibitory and excitatory effects between 'hypotheses–cells' cause a relaxation process towards a more consistent set of hypotheses.

In our model philosophy the 'recognition' of a sensory situation and the selection of appropriate behaviour is based on the generation of sequences of hypotheses (**figure 3**). Supposing the following coincidences have been detected formerly: if in a sensory situation **S1** a motor command **M1** is executed, a new situation **S2** is set up, the same being valid for **S2-M2** and **S3** as well as **S2-M3** and **S4**. **S3** and **S4** at the end of different sequences of hypotheses are assumed to be coincident with sensory situations of a genetically determined negative (pain) or positive (pleasure) meaning for the living being. Starting now from a given situation or event **S1**, different sequences are induced (in parallel or successively) by random activation of the motor command units below a level necessary for execution. In the hypothetical situation **S2** the generation process can take two different ways in dependence of the random excitation of **M2** or **M3**. If the chain of predicted events ends at a *negative impression* (**S1-M1→S2-M2→S3**), all motor command neurons which took part in the generation of this special sequence are suppressed by negative feedback, that is, actions supporting the real course predicted by the sequence of hypotheses cannot be executed. If the event is coincident with a *positive impression* (**S1-M1→S2-M3→S4**), the sequence is preferred for execution due to accumulation of excitatory feedback at the motor command neurons. The selection of appropriate behaviour in a given situation could be realized this way.
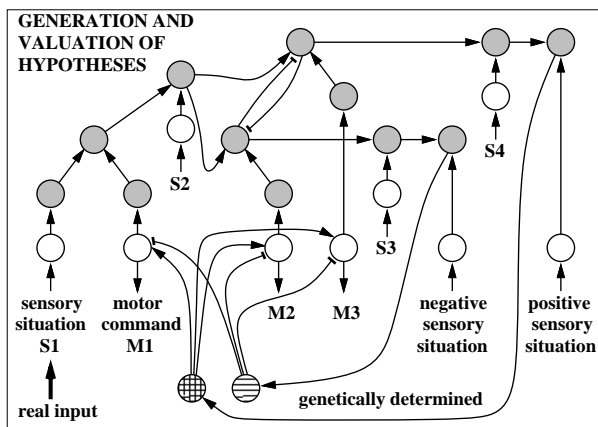

Figure3: The selection of appropriate behaviour in a given situation **S1**. If in this situation a motor command **M1** is executed, an new situation **S2** emerges. The execution of **M2** in the situation **S2** leads to a new situation **S3**, which itself was found to be coincident with a negative impression. In this case all motor commands involved in the sequence are suppressed. If **M3** is executed in the situation **S2**, a 'positive' situation **S4** arises — the corresponding motor commands become candidates for execution.

Random stimulation of motor command neurons appears in two forms. Stimulation *above* a level necessary for execution provokes 'sensory reactions' of the physical world. That is the way to detect coincidences between an action and its sensory consequences. If the corresponding coincidences have

already been detected, stimulation *below* this level does not entail any action but may predict the sensory consequences of it in a certain situation.

4. Visual recognition

Recognition of *shape* is considered to be a basic function of the visual system: classification of an object requires the recognition of its functional properties [3], functional properties can only be recognized if the shape of the object is perceived. In our approach, visual perception of shape at higher processing levels can be explained by the detection of stable relations between visual information and information from other senses (multimodal processing) during activities in the environment. Visual information is connected to impressions like 'time-to-contact', when a certain movement is executed, or tactile information, when an object is grasped. Once having detected coincidences of this kind, visual information itself is sufficient to characterize the shape *by a sum of related actions and impressions which are typical for it.* The internal representation of perception of shape would be in our model a multitude of sequences of hypotheses about the consequences of different actions, induced in parallel or successively by the given visual information (a distributed representation of sensory and motor information relevant for the situation). These actions don't have to be executed, they only describe the visual scenery, but those actions, which are a starting point of one of the 'positive' sequences of hypotheses, are candidates for execution as described above.

Applying our approach to perception of shape could help to avoid problems arising from an artificial separation between recognition and generation of behaviour. If both parts are separated, a 'unit for recognition' has to analyze the visual information and to convert it into any descriptive code, whereas another 'unit for generation of behaviour' converts this code into appropriate behaviour. First, the descriptive code can be more compact than the visual information itself, but its interpretation is not necessarily simpler. Second, the conversion into a descriptive code could be a detour. If an object partially covered by another shall be grasped, knowledge about covering has to be applied, covering has to be expressed in a desriptive code, and by use of knowlegde about appropriate movements for grasping in the case of covering, motoric commands have to be derived from the code. It seems to be much simpler to characterize the visual scenery *immediately* by a sum of hypotheses about the consequences of actions possible in this situation; from this set of sequences of hypotheses appropriate behaviour is chosen.

Our model hypothesis should be understood as a first alternative approach to a general model of complex visual perception; perhaps it could be possible to explain some processes using more elaborate networks (e.g. those capable of generalizing detected coincidences) composed of the simple units described in this paper.

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